Section 954
Issue No. 1
December 1982

DIGITAL TERMINALS AND MULTIPLEXERS

CONTENTS

1. GENERAL

1.1 This section provides REA borrowers, consulting engineers and other interested parties with information and recommendations on digital transmission systems. The section specifically covers digital terminal equipment, or channel banks. Digital multiplexers, terminal maintenance systems and alarms are briefly covered also. Refer to TE&CM Section 950 for an overview and summary discussion on digital transmission, and refer to TE&CM Section 951 for a glossary of digital transmission terminology. Digital span lines, span line interrogation and automatic protection switches (APS) are covered in TE&CM Section 956.

1.2 In general, a digital channel bank or terminal consists of the necessary equipment to encode and decode analog signals (voice and signaling) into a digital bit stream. Channel banks are generally arranged in 24 channel groups, or in multiples of 24 channels. Certain interface criteria are specfied or otherwise implied by equipment specifications, application, or commonly used terminology. REA Specifications PE-60 and PE-64 outline some of these requirements. While other equipment types and encoding processes are discussed, terminal equipment or channel banks referenced in this section generally refer to adaptations of the D3 type channel bank transmitted over T1 type span lines. This implies 24 voice channels (with signaling), sampled at 8000 times per second, utilizing a $\mu = 255$ companding law, encoded into 8 bits per sample representing 255 coding levels and resulting in a 1,544 Mb/s bit stream of defined characteristics such as density, height, width and shape.

1.3 Currently, most digital information is transmitted at the DS1 rate of 1.544 Mb/s over T1 type span lines on paired telephone cables. Basic DS1 signals are also combined or multiplexed to form higher rate digital signals for transmission over paired cables, radio, optical fibers and coaxial cables. A brief discussion of digital multiplexers is included in this section to provide a description of how the separate, nonsynchronized DS1 signal inputs are multiplexed to form a higher bit rate synchronized output. The discussion is limited in scope, and is not intended as a complete discussion of specific multiplex equipment.

2. DIGITAL TECHNIQUES AND CHARACTERISTICS

2.1 This discussion summarizes some of the techniques used for digital encoding, transmission and multiplexing. Technical characteristics of the digital signals and the decoded analog signals of several techniques are briefly reviewed and compared. Emphasis is placed on D3 voice encoding as a telephone industry standard.

2.1.1 Digital transmission systems began in trunk service as Western Electric D1 channel banks (and T1 span lines). From this evolved the D1A, D1B, D1C, D1D, D2, D3 and D4 channel banks for trunk service, and variations of D1, D3 and differential PCM for subscriber service. The independent manufacturers generally provided versatile channel banks that were made compatible with several Western Electric channel banks by strapping options or special plug in cards.

2.1.2 Digital systems for voice transmission use nonlinear encoding (unequal coding steps). With early terminals, this was accomplished by instantaneous compandors (compressors and expandors) and linear coders and decoders (equal coding steps). Later terminals utilize nonlinear encoders and decoders to achieve the same (or improved) results. Nonlinear encoding (by using either a compandor or by direct nonlinear encoding) provides much improvement in voice quality with fewer coding steps. Many times the number of coding steps would be required with equal coding steps. The coding steps are small for low level samples and larger for high level samples. The nonlinear coding steps for digital systems are determined by a "companding law" of $\mu = 100$ for D1 channel banks and $\mu = 255$ for D2, D3 and D4 channel banks. European systems use an "A law" compandor; but digital systems in North America are now standardized on the companding law of $\mu = 255$.

2.2 <u>Trunk Systems</u>: The following is a brief summary of channel bank characteristics used for trunk service.

2.2.1 <u>D1</u>: The D1 channel bank was the first digital channel bank used in telephony. The analog voice signal was fed into an instantaneous compandor before encoding. The voice was sampled and fed into a bus containing pulse amplitude modulated (PAM) signals from 12 of the 24 channels. The PAM signals were compressed utilizing a $\mu = 100$ law, encoded into 7 bits per PAM sample representing 127 coding levels. A signaling bit was added for each voice encoded sample, and a framing bit was added at the end of each 24 channel sequence. This results in 24 x 8 = 192 + 1 = 193 bits per frame x 8000 frames/second = 1.544 Mb/s. Because the system used two compandors, the channel sequence was 1, 13, 2, 14, 3, 15, etc. Channels 1 through 12 were fed into one compandor and 13 through 24 into the second compandor. This was done to reduce crosstalk in adjacent time slots.

2.2.2 D1A: The D1 channel bank was later designated as the D1A channel bank. The D1A channel bank used one of the eight bits assigned per channel each frame to provide one signaling channel for each voice channel. Some PCM channels require two signaling channels. To accomplish this with D1A channel banks, a bit normally assigned for voice encoding was used. This left only 6 bits for voice encoding, resulting in greater noise and distortion during this signaling condition.

2.2.3 D1B: The D1B channel bank is the same as the D1A, except that the signaling bit was divided into four segment (a super frame of four frames) to provide two signaling channels. This allowed the seven remaining bits to be used for voice encoding at all times. The independent manufacturers provided D1 channel banks that could be arranged for either D1A or D1B signaling.

2.2.4 D1C: The D1C was a special purpose D1 channel bank used in TSPS applications. The signaling bit for all 24 voice channels were combined into a separate high speed data channel (192 kb/s).

2.2.5 D1D: After D2 and D3 channel banks were placed in service, Western Electric developed a modified version of the D1 channel bank to achieve D3 voice quality. This was designated the D1D, and was developed to utilize the large quantities of D1 racks and shelves already installed. The independent manufacturers utilized D3 channel banks to meet D1D application requirements by changing the channel sequence from 1, 2, 3, 4, etc., (for D3) to 1, 13, 2, 14, etc. (for D1). This change was accomplish by a plug-in card or by a change in channel bank backplane wiring, depending on the specific type and age of equipment.

2.2.6 D2: The D2 channel bank was developed to achieve a higher quality voice circuit for intertoll applications. The D2 bank utilizes 8 bit non linear voice encoding to derive 255 coding levels. The non linear coding steps are determined by a companding law of $\mu = 255$. Two signaling channels are providing by "robbing" the least significant voice bit every sixth frame. On the sixth frame, signaling channel A is transmitted; and on the 12th frame, signaling channel B is transmitted. Twelve frames are a super frame, and the sequence repeats. The Western Electric D2 was designed in 96 channel groups for T1 application (24 channels) and T2 application (96 channels). The Independent manufacturers responded to Independent telco needs by designing D2 channel banks in 24 channel groups. The D2 channel sequence is 12, 13, 1, 17 , 5, 21 etc. Independent manufacturers' equipment can be arranged for D2, D3 or D1D application by changing the channel sequence (and perhaps other minor considerations).

2.2.7 D3: The Western Electric D3 channel bank was designed in 24 channel groups for T1 application to provide the same voice quality of D2 channel banks. The channel sequence is 1, 2, 3, 4, etc. The Independent manufacturers D2 was easily redesigned to cover both D2 and D3 applications. (Field modification of early D2 systems for D3 application were sometimes awkward to accomplish.) D3 is considered the standard for all digital equipment in production today. The D3 format is used in all trunk applications, including high density applications such as optical fiber systems and direct digital interface of digital central office equipment. The D3 voice encoding is used for digital subscriber equipment; however, the use of signaling and framing bits vary with equipment. The channel sequence for D banks is:

Time Slots	D1	D2	D3
1	1	12	1
2	13	13	2
3	2	1	3
4	14	17	4
5	3	5	5
6	15	21	6
7	4	9	7
8	16	15	8
9	5	3	9
10	17	19	10
11	6	7	11
12	18	23	12
13	7	11	13
14	19	14	14
15	8	2	15
16	20	18	16
17	9	6	17
18	21	22	18
19	10	10	19
20	22	16	20
21	11	4	21
22	23	20	22
23	12	8	23
24	24	24	24

2.2.8 D4: The D4 type channel bank is designed in 48 channel groups for T1, T1C and T2 span line application. The D4 channel bank is essentially a lower cost, smaller combined packaging of two D3 channel banks (24 channels each). The D4 channel bank is arranged for five modes of operation, with Mode 3 being the same as two D3 channel banks. D3 and D4 are covered in more specific detail in paragraph 3.

2.3 Subscriber Systems: The following is a brief summary of characteristics of systems used for subscriber service.

2.3.1 D1 Subscriber: Early versions of PCM subscriber carrier and integrated carrier - concentrators used D1 voice encoding. The signaling bit was generally used on a per channel basis (8 kb/s per channel) to encode and initiate dialing, ringing (including a variety of multiparty ringing), other signaling, supervision, and test functions. Alarms, status reporting and similar functions were usually handled on a system basis. Integrated carrier-concentrators generally used the signaling bits from all channels on a serial bit stream basis (192 kb/s) to instruct microprocessors to initiate all signaling, switching, alarm, status and test functions. PCM subscriber carrier was generally packaged in 24 or 48 channel groups for transmission over T1 span lines. One system provided 36 channels using ternary encoding (three level pulse stream) utilizing a special span line near the T1 rate.

2.3.2 D3 Subscriber: PCM subscriber carrier and integrated carrier-concentrators have standardized on the use of D3 voice encoding and most other D3 system characteristics, except signaling. Present day D3 subscriber carrier systems generally use the signaling bits on a per channel basis ($8000 \div 6 = 1333$ b/s per channel). Integrated carrier-concentrators

generally use the signaling bits from all channels on a serial bit stream basis (32 kb/s) to interface with microprocessors. With the present microprocessor cost trend, more use of microprocessors is expected in D3 subscriber carrier equipment also. D3 subscriber carrier is covered in more specific detail in paragraph 3.

2.3.3 DPCM Subscriber: Differential PCM (DPCM) is a technique for encoding and transmitting changes in amplitude of analog voice signals. This is often called delta modulation, in reference to the fact that the encoded signal represents a change in amplitude rather than an absolute level. Acceptable voice quality was attained with a per channel rate of 32 kb/s to 40 kb/s in subscriber service. This was more efficient than the 64 kb/s per channel rate (including signaling) required for D3 PCM. Compared to D3 PCM, the DPCM technique has advantages and disadvantages. Several DPCM subscriber carrier and carrier-concentrator systems were developed and placed into service. Production of DPCM equipment has been discontinued because of standardization on D3 voice encoding for all voice services in telephony.

2.4 Multiplex Systems: The digital channel bank performs the first level of multiplexing by encoding 24 voice channels into a digital pulse stream suitable for universal interface and efficient transmission over paired cables. Basic DS1 signals are also combined or multiplexed to form higher rate digital signals. There is a range of digital multiplex equipment that combines two or more asynchronous inputs into higher rate synchronized outputs. Some multiplexers interleave the separate input bit streams on a bit-by-bit basis, and other interleave the inputs in groups of bits. Generally, the multiplexers are designed to interface at the DS1 or other standard signal level in the Bell System hierarchy, but may not follow the specific signal format or bit rate outlined for standard Bell System M-type multiplexers on both the input and output interfaces. Similar techniques are generally used for scrambling, stuffing and temporary storage of bits in the multiplexing process.

2.4.1 The following is a generalized description of a multiplexer, using the M12 as a model. The multiplexer accepts four asynchronous DS1 inputs and combines them into a synchronized DS2 output. The four inputs are interleaved into a single output without regard to the information content of each. (That is, no attempt is made to synchronize the inputs into frames or super frames before multiplexing.) Prior to multiplexing, the second and fourth input signals are inverted (ones become zeros and zeros become ones) as a first stage of randomizing the multiplexed output. Bits are extracted from each input in groups of 12 bits and interleaved into a single bit stream and one control bit is added (12 + 12 + 12 + 12 + 1 = 49 bits). This sequence is repeated six times to form a subframe (49 x 6 = 294 bits). The subframe sequence is repeated four times to form a frame (294 x 4 = 1176 bits). Of the 1176 bits in a frame, 1152 are information bits from the four DS1 inputs and 24 are for control.

2.4.2 The four inputs are not synchronized, so they are fed into a buffer store or elastic store so they may be extracted at the exact time required. The inputs not only lack phase synchronization, but also lack frequency synchronization; that is, each may be running at a different speed or bit rate. Some of the input stores will become empty before others. Extra bits are added to the bit streams (stuffed) as required to keep the stores from becoming empty. Stuffed bits can be added only at specified locations (time slots) in the bit stream, and the control bits identify when

a stuffed bit has been added.

2.4.3 The 24 control bits per frame are separated into four "M" bits, eight "F" bits and twelve "C" bits. An M bit begins each subframe. The M bit pattern of ones and zeros line up the 294 bit subframes, the 1176 bit frames and transmit alarm information from the transmitter to the receiver. The pattern of the F bits and C bits further line up each subframe, and line up possible stuff bit time slots, and identify if stuff bits are transmitted. The stuff bits are added to each DS1 input as required; and , if added, takes the place of one DS1 information bit (that was not available at the time required). This provides for a maximum of 5367 stuffed bits per second for each DS1 input (about 0.3 percent of the output bit stream). The clocks driving individual DS1 inputs do not require high level precision, but must remain within specified limits.

2.4.4 The multiplexer output bit rate is the sum of the all bit stream inputs plus a fixed number of control and framing bits plus a flexible number of stuffed bits. The output is processed to ensure that no more than five consecutive zeros are transmitted. This is the final stage of scrambling. The following are examples of standardized Bell System M-type multiplexers. The characteristics of the DS line signals are discussed in paragraph 2.5.

Multiplex	Input	Output	Channels
M1C	2 DS1	DS1C	48
M12	4 DS1	DS2	96
M13	28 DS1	DS3	672
M23	7 DS2	DS3	672
M34	6 DS3	DS4	4032

2.5 Transmission and Multiplex Signals: Digital channel banks and multiplex equipment encode and combine digital signals into a bit stream suitable for efficient transmission and interface. Several of these encoding and format techniques are discussed and the signal characteristics are briefly outlined. Included topics are unipolar and bipolar pulses, random and repetitive pulse patterns, scrambling, ternary and duobinary encoding, pulse stuffing, buffer stores, and zero substitution codes.

2.5.1 Unipolar Pulses: Unipolar pulses (one polarity) are used within equipment and local systems, but are not generally transmitted over any distance. Unipolar pulses can be converted into other line signals by any of the techniques used for digital transmission; the most common technique used is bipolar pulse transmission.

2.5.2 Bipolar Pulses: Bipolar pulses are generally used for transmission over exchange cable pairs. Unipolar pulses used in equipment are easily converted into bipolar pulses, alternating in polarity (alternate bipolar pulses). Bipolar pulse transmission has several advantages over unipolar pulse transmission. These are illustrated in Figure 2 based on a random T1 bit stream at 1.544 Mb/s. The advantages include the following:

a. Power is concentrated near 772 kHz.
b. Low frequency power is reduced (no dc).
c. High frequency power is reduced.
d. Errors can easily be recognized.

2.5.2.1 In this discussion of bipolar pulse transmission, it is generally assumed that the pulses are random and contain no bipolar violations (consecutive pulses of the same polarity). Most systems are designed to transmit alternate bipolar pulses with no violations. By design, some systems contain low density bipolar violations, and others such as ternary encoding contain a large quantity of bipolar violations. In these cases, the bipolar violation or pulse polarity convey information. To transmit and recover signals with bipolar violations requires the system to pass low frequencies, perhaps near dc.

2.5.2.2 By design or otherwise, certain repetitive patterns are generated. These repetitive patterns may be greater during no traffic or low traffic conditions. Framing pulses are necessarily repetitive and will produce low level 8000 hertz and perhaps other signals. Of greater interest are the repetitive patterns resulting from the no traffic or low traffic condition. By design, the following patterns are generated in the idle, on hook condition. (Framing pulses are excluded in this comparison.) D1A transmits two pulses in 8 bits each frame. This results in large power concentrations at multiples of 193 kHz. D1B transmits one pulse in 8 bits three out of four frames and two pulses in 8 bits for the remaining one out of four frames. This results in large power concentrations at multiples of 96.5 kHz. The pulse density was increased in D3 systems to improve system stability (more pulses for clock timing). D3 transmits 8 pulses in 8 bits during the idle condition. This concentrates the power near 772 kHz. The only one of the above conditions that cause any concern with carrier system applications is the one pulse in 8 bit condition. This could cause interference in certain station carrier channels when PCM and station carrier are applied in the same cable. In reality, some random pulses may be generated due to noise or equipment conditions. These random pulses tend to spread the power somewhat but the system can still transmit large discrete power components. The power spectrum of D1 and D3 under traffic conditions is very similar. With a slightly larger pulse density, the D3 power is slightly lower at low frequencies and slightly higher near 772 kHz.

2.5.3 Scrambling: Various techniques are used to "scramble" or "condition" the digital bit stream for modulation or transmission. Scrambling is used to avoid long groups of consecutive zeros or repetitive patterns in the transmitted signal. The object is to keep the signal in a dynamic state of random change. Scrambling may be required because of the modulation techniques or may be used to improve system performance. The scrambler rearranges the digital bit stream in a predetermined manner to produce a random-appearing sequence of bits. The descrambler at the receiver restores the digital bit stream to its original form. Scrambling is sometimes used in paired cable digital transmission systems to maximize performance. Scrambling is commonplace in higher order systems such as radio, lightwave and coaxial cable systems because of modulation techniques and to reduce system loading. Error rate in the scrambled bit stream must be several times better than a non scrambled bit stream. The process of descrambling will increase the error rate of the received signal.

2.5.4 Ternary Encoding: Ternary encoding is used to increase the information rate with a smaller corresponding increase in the transmitted span line signal rate. Ternary refers to three states such as positive, negative and zero. Ternary is a bipolar signal where the presence and polarity of pulses convey information. One ternary encoded transmission system uses a four binary to three ternary (4B3T) code to transmit four information bits in three time slots. This converts a 48 channel 3.152 Mb/s binary signal into a 2.364 Mb/s ternary signal. The span line signal is processed in a manner that imposes a small increase in the facility requirements (compared to T1) for exchange cable applications. There is a large quantity of bipolar violations contained in the ternary encoded pulse stream.

2.5.5 Duobinary Encoding: Duobinary encoding is a technique used to double the information rate with a small increase in the facility requirements (compared to T1) for exchange cable applications. A modified duobinary encoded system divides a T1C stream into two alternative bit streams, and then interleaves the two signals in a duobinary format. A T1C system transmits pulses of 158 nanoseconds duration of the 317 nanoseconds time slot allotment (50 percent duty). The duobinary system takes advantage of the "dead time" between pulses. One hundred percent duty pulses are transmitted (317 nanosecond pulses in a 317 nanosecond time slot). The two bit streams are interleaved each 317 nanoseconds, and the resultant combined output pulses may be either 158 or 317 nanoseconds wide (one or two time periods) before returning to zero. The duobinary signal transports the T1C information rate but with a power spectrum similar to that of a T1 system.

2.5.6 Pulse Stuffing: Pulse stuffing, or more correctly, bit stuffing is a method used for synchronizing two or more asynchronous bit streams in a multiplexer. Extra noninformation bits are inserted (stuffed) as required at the multiplexing end and are removed at the demultiplexing end.

2.5.7 Buffer Stores: A buffer store or elastic store is a temporary storage unit for digital information (a temporary memory for binary digits). Buffer stores are used in digital multiplexers to combine two or more asynchronous inputs into a synchronous output. The buffer store is used to separate the store (write in) and extract (read out) speeds. The buffer store in combination with bit stuffing provides for multiple asynchronous inputs to be temporarily stored, and to be extracted as a synchronized combined output. The output rate will be the sum of all bit stream inputs plus a fixed number of framing and control bits plus a flexible number of stuffed bits. The size of the store (number of stored bits) depends on how frequently stuffing bits can be inserted into the bit stream. The store must never be allowed to become "empty". Frequent stuffs allow for smaller stores.

2.5.8 Zero Substitution Codes: Zero substitution codes are used to avoid transmitting long strings of consecutive zeros. Zero substitution is often a final stage of scrambling in a digital multiplexer to maintain a dynamic output signal. The DS2 line signal is a 50 percent duty bipolar pulse stream with controlled bipolar violations. The bipolar format is called "bipolar with six-zero substitution" (B6ZS). The multiplexer allows no more than five consecutive zeros to be transmitted. Six consecutive zeros are converted into positive pulses, negative pulses and zeros containing a pattern of bipolar violations to identify this conversion.

2.5.9 Line Signals Characteristics: Digital line signal characteristics are specified by the Bell System for standard interface. The specifications outline bit rates, signal format (time slot assignment) signal waveshape and other characteristics. The following outlines some of these design characteristics.

Level	Rate Mb/s	Pulse/Duty	Notes
DS1	1.544	Bipolar/50%	-
DS1C	3.152	Bipolar/50%	-
DS2	6.312	Bipolar/50%	B6ZS
DS3	44.736	Bipolar/50%	B3ZS
DS4	274.176	Polar/100%	NRZ

2.5.9.1 The DS1, DS1C, DS2 and DS3 line signals are transmitted as bipolar pulses. DS1 can contain no more than 15 consecutive zeros. DS1 and DS2 contain no bipolar violations. DS3 and DS4 contain bipolar violations to identify zero substitution codes (B6ZS and B3ZS). DS4 is transmitted as a 100 percent duty, nonreturn-to-zero (NRZ) polar signal where positive represents a logic one and negative represents a logic zero. The NRZ signal must be kept in a dynamic condition.

2.5.9.2 With standard signal formats, each bit has a special identity or significance when processed with other bits. However, the bit stream must be descrambled and stuffed pulses removed before a DS1 bit stream can be used as a unit, or separated into 64 kb/s channels.

3. PRESENT DAY EQUIPMENT

3.1 The D3 channel bank or an adaptation of D3 has become the standard for digital terminal equipment, and for integrated digital transmission and switching systems. A brief description of D3 and D4 trunk carrier equipment and PCM (D3) subscriber carrier equipment is provided. This carrier equipment may interface the central office on a per channel voice frequency basis, or may interface on a digital bit stream basis.

3.2 D3 Channel Bank: Present day digital trunk carrier is typified by the D3 channel bank. There are variations in manufacturers' equipment, but Figure 1 serves to illustrate the D3 functions. The encoding and decoding process will be described, using Figure 1 as a guide. (Also refer to TE&CM Section 950, Appendix A.)

3.2.1 Analog voice signals enter the voice frequency hybrid (on two-wire channels) for separation into transmit and receive directions. For satisfactory service, a time division system (TDM) must sample at twice the highest frequency to be transmitted. Since D3 samples at 8000 times per second, frequencies above 4000 hertz cannot be transmitted and must be eliminated before sampling. The voice signals are passed through a low pass filter to attenuate signals above 3500 hertz. Because of equipment design and noise considerations, frequencies below 200 hertz are also attenuated. Using a relatively precise clock, the voice signals are sampled 8000 times per second and converted into discrete voltage levels corresponding to the sampled analog signal. This is called pulse amplitude modulation (PAM). The PAM signals from each channel are fed through a gate and into a PAM bus, with each channel in sequence (1, 2, 3, 4, etc.).

3.2.2 Each PAM signal is converted into "bits" of encoded information (ones and zeros) at the encoder. Each group of bits represents a specific PAM voltage. D3 channel banks use an eight bit code, allowing for 256 possible code levels. The D3 uses 127 positive levels, 127 negative levels, and zero, or 255 code levels. The all zero code is omitted; zero level is transmitted as all ones. D3 channel banks use nonlinear encoders and decoders (unequal coding steps) to improve the voice quality with fewer coding steps. The coding steps are small for low level samples (i.e., 1 mv) and larger for high level samples (i.e., 128 mv). From the encoder, the bits appear on the PCM bus as unipolar pulses (in groups of 8) in proper channel sequence. The sampling of 24 channels in sequence is called a frame. An extra information bit is added at the end of each frame, and is called the framing bit. There are 8 bits per channel times 24 channels equals 192 bits, plus one framing bit equals 193 bits per frame. 193 bits per frame times 8000 frames per second equals 1,544,000 bits per second. This is the T1 or DS1 rate, and is chosen as the basic building block for digital transmission in North America.

3.2.3 The framing bits are used to synchronize the receiver with the transmitter. The framing bits are generated in the transmitter in a special sequence so that the receiver can separate the bit stream for proper timing and framing. These framing bits are in a special sequence of ones and zeros for 12 frames, and then repeated. The 12 frames are called a super frame. The framing bit pattern for frames one to 12 is 100011011100. A closer review of this pattern shows that the odd framing bits (1, 3, 5, etc.) contains a 101010 pattern, and the even framing bits contain a pattern of 000111 (begin with the 12th frame). Considering only even frames, the bit changes on the 6th and 12th frames. Signaling information is entered on the 6th and 12th frames. (Note: Signaling and superframe characteristics are subject to change in the future.)

3.2.4 Voice and signaling bits for each channel are merged in the "output". One of the 8 voice bits (B8 - the least significant bit) is "robbed" and used for signaling information each 6th frame. (The voice encoding is actually 7 5/6 bit encoding, or almost 8 bit encoding.) There are two signaling channels. For each voice channel, one bit of signaling is transmitted during the 6th frame (signaling channel A) and another signaling bit is transmitted during the 12th frame (signaling channel B). Each signaling channel contains 8000 ÷ 6 = 1333 bits per second. The signaling channels transmit all of the dialing, ringing and supervisory information from one terminal to another. The 1.544 Mb/s bit stream now contains voice and signaling information as unipolar pulses. The unipolar pulses are fed into a bipolar converter for transmission on paired telephone cable. The reasons for bipolar conversion were discussed in paragraphs 2.4.1 and 2.4.2 and are illustrated in Figure 2.

3.2.5 The master clock in present day equipment can be driven from an internal 1.544 Mhz ± 50 Hz generator; or can be synchronized locally or on the received bit stream for synchronous operation such as a direct interface into the digital COE. The ± 50 Hz generator stability is unnecessary for nonsynchronous operation, but is established primarily to narrow the "pull-in" range of the transmitter for synchronous operation. Where channel banks provide the terminations at both ends of a system, the transmitter at each end independently generates its 1.544 Mb/s. The receivers clock on the incoming bit streams; no other synchronization of signals is necessary, and a relatively wide frequency variation could be tolerated

(i.e., ± 200 Hz).

3.2.6 The receiver functions much like the transmitter, only in reverse. The decoding process will be outlined only briefly. The bipolar bit stream is received and converted into unipolar pulses. Timing and framing information is extracted from the received bit stream to synchronize the receiver. (As noted above, the received bit stream also controls the transmitter when the system is synchronized on a distant digital COE.) The input separates the voice and signaling bits. The decoder converts the voice bits into a PAM signal. This PAM signal is gated into the proper channel through a low pass filter. The low pass filter attenuates frequencies above 3500 hertz, and aids in reconstructing a voice signal much like the original signal. Some residual distortion remains because of the limited number of encoding levels and the sampling rate. The analog voice signal is then amplified and passed through the voice frequency hybrid into the analog telephone network.

3.2.7 The following is a summary of D3 characteristics. A frequency near 1000 hertz (1004 or 1020 hertz) is used to measure signal-to-distortion and level tracking.

<u>Channel Noise</u>: 23 dBrnc0 Maximum

<u>Bandwidth</u>: Approximately 250 to 3500 Hz

<u>Signal-to-Distortion</u>:

Input (dBm0)	S/D Minimum (dB)
0 to -30	33
-30 to -40	27
-40 to -45	22

<u>Level Tracking</u>:

Input (dBm0)	Maximum Deviation (dB)
+3 to -37	0.5
-37 to -50	1.0

3.2.8 A typical arrangement of a D3 channel bank is illustrated in Figure 3. It generally consists of 24 channel cards and a section for common equipment. Typical common equipment consists of a transmit card, a receive card, alarm card and power supply. A card slot is generally available to insert a specialized PCM test set for alignment and maintenance. On separate shelves serving several channel banks are span terminating equipment, patching jacks, and other specialized test and service units. The most common channel units offered are:

4 Wire E&M	(600 ohms)
2 Wire E&M	(600 or 900 ohms)
2 Wire Dial Pulse Originating	(600 or 900 ohms)
2 Wire Dial Pulse Terminating	(600 or 900 ohms)
4 Wire Without Signaling	(600 ohms)

3.2.9 The channel bank shelves and common equipment that are integral to the channel bank are often identical for digital trunk and subscriber systems. (The ancillary equipment may be different.) Trunk, subscriber and special service channels can generally be mixed within a trunk or subscriber channel bank. Refer to paragraph 3.4 for subscriber and special service channels.

3.3 D4 Channel Bank: The D4 type channel bank is designed in 48 channel groups for T1, T1C and T2 span line application. The D4 channel bank is essentially a lower cost, smaller combined packaging of two D3 channel banks (24 channels each). The D4 channel bank is arranged for five modes of operation, with Mode 3 being the same as two D3 channel banks. These are shown in Figure 4.

3.3.1 D4, Mode 1: In D4, Mode 1, 48 channels are combined and operated at the DS1C level over a T1C span line (3.152 Mb/s). The transmit unit combines two synchronized DS1 signals (1.544 Mb/s each) and adds framing bits (64 kb/s). Both 24 channel groups are synchronized.

3.3.2 D4, Mode 2: In D4, Mode 2, 48 channels are combined as if they were two D3 channel banks (synchronized, or nonsynchronized). Two groups of 24 channels (at 1.544 Mb/s) are combined using an M1C equivalent multiplexer and operated at the DS1C level over a T1C span line (3.152 Mb/s). The distant terminal consists of two colocated or separate D3 type channel banks and an M1C multiplexer. Mode 2 differs from Mode 1 in that Mode 2 uses an M1C frame format and that the 24 channel groups do not require synchronization.

3.3.3 D4, Mode 3: In D4, Mode 3, 48 channels are operated independently the same as two separate D3 channel banks over two T1 span lines (1.544 Mb/s).

3.3.4 D4, Mode 4: In D4, Mode 4, two colocated 48 channel D4 groups are combined and operated at the DS2 level over a T2 span line (6.312 Mb/s). The distant end could be D4, Mode 4; or could be at one to four terminal locations of 24 channel groups operated over T1 span lines (1.544 Mb/s) and combined with an M12 multiplexer at a common location.

3.3.5 D4, Mode 5: Mode 5 of D4 is the same as Mode 4, except that the DS2 interface is optical rather than electrical. Two colocated 48 channel D4 groups are combined and operated at the DS2 level over an optical fiber system at 6.312 Mb/s. As with Mode 4, the distant end could be colocated D4 channel banks; or could be one to four terminal locations after conversion from an optical to an electrical bit stream.

3.3.6 The D4 channel banks generally use a codec per channel, rather than shared codecs as used in D3 and earlier channel banks. This provides easy access to the bit stream for high speed data. The 1.544 Mb/s bit stream can be accessed in multiples of 64 kb/s for each voice channel displaced (including signaling), or in multiples of 56 kb/s with B8 used exclusively for signaling. (The identity of B8 for voice and data use may be lost as the bit stream is processed through digital switches. This is discussed in paragraph 3.6.3).

3.3.7 Note that D4, Modes 1, 2 and 4 require multiplexers to operate at DS1C and DS2 rates. These multiplexers are plug-in cards in the D4 channel bank. Few equipment changes are required to change from one operation mode to another. With the multiplexers designed as an integral part of the D4 channel bank, costs are reduced for D4, Modes 1, 2 and 4 over the mating hardware using D3 channel banks.

3.4 PCM Subscriber Carrier: The model for present day PCM subscriber carrier is the D3 trunk carrier channel bank. Some areas of the specification requirements may be relaxed slightly where D3 is used for subscriber service. The carrier system subscriber channel is, in effect, a central office line circuit that has been moved to a field location. It is not an exact duplicate of the COE line circuit, but does extend some of the basic line circuit functions to a remote location. PCM subscriber carrier systems generally use D3 voice encoding. The signaling bits along with perhaps framing bits and inband tones are used for various signaling, status reporting, testing, alarm and other functions. These functions are not standardized between equipment types.

3.4.1 Dialing is accomplished in PCM subscriber carrier much like the trunk carrier. The signaling bits simply denote on-hook and off-hook conditions. To avoid COE overload, subscriber systems generally go into an on-hook condition during failure rather than the disconnect-and-make-busy condition used with trunk systems. The on-hook and off-hook signaling can easily be handled by one signaling channel; this leaves the second signaling channel for other functions.

3.4.2 Single party ringing in PCM subscriber carrier is generally accomplished by switching a common ringing generator into the channel circuit to be rung. The ringing generator is generally a 20 hertz sine wave generator; it may lack a high degree of frequency stability and be intended for straight line ringer application only.

3.4.3 Multiparty ringing may be accomplished with a single frequency (20 hertz) and side of line identification. However, bridged frequency ringing (BFR) is more common in rural areas. Each channel at the subscriber terminal either amplifies or regenerates a ringing voltage between 16 and 66 hertz that corresponds to the assigned ringing frequency into the CO channel. Various means are used to transmit this information from the office to subscriber terminal. A common method is to use signaling bits to initiate ringing, and to also transmit a modulated tone at the ringing frequency over the voice circuit. The ringing voltage is reconstructed by each subscriber channel. Modified square waves are commonly generated because it is not practical to generate sine waves in this manner. With the use of microprocessors, multifrequency sine wave ringing may be practical in the future.

3.4.4 Other signaling functions can also be accomplished with subscriber carrier such as foreign exchange and paystation signaling. These special service channels are generally arranged to be compatible with trunk and subscriber channel banks on a plug-in basis.

3.4.5 Distributed channels of PCM subscriber carrier are technically practical. It is practical to terminate PCM channels in small groups, or even one channel per location. Similar drop and insert techniques are now used on digital radio systems. The economics of distributed PCM subscriber carrier

is generally not favorable at this time. The equivalent of a channel bank common equipment is required at each terminal location. AC power will be required occasionally along the route, but not necessarily at each terminal location. The real push in this area may come from the need to provide high speed data to business customers sometime in the future. On a more limited scale, distributed subscriber carrier is available. For basic telephone service, one existing PCM subscriber carrier system can be terminated in 8 channel groups at up to three locations.

3.5 Alarms and Maintenance: Alarm, maintenance and test functions are relatively easy to initiate, transmit and register using digital techniques. There is a wide range of alarm and maintenance hardware available now, and microprocessor development is continuing to enhance this capability. Present capability ranges from simple alarm indications to large centralized maintenance systems. Some of the basic alarm and maintenance functions are standardized for trunk systems; but the majority of these functions are not standardized, especially for subscriber systems. The ability to provide elaborate alarm, test or control functions from a remote location is limited primarily by economics and not by technology. Digital subscriber systems are being applied in larger quantities per location. Functions that are not economically practical for distributed subscriber systems become more practical as circuit quantities per location increase. Alarm, maintenance and test features of digital systems are already highly developed, and should become even more practical and economical in the future. The following is a summary disucssion covering alarm and maintenance techniques primarily for terminal and multiplex equipment. Refer to TE&CM Section 956 for a discussion on span line interrogation and automatic protection switching.

3.5.1 In the digital trunk network, basic alarm indications are generated in terminal and multiplex equipment, and this information is transmitted to distant locations as an integral part of the bit stream. For universal interface, Bell System specifications identify certain alarm conditions and specify how the information is to be transmitted.

3.5.2 Channel banks in trunk service have standard red and yellow alarm indicators incorporated in the equipment. A red alarm indicates the loss of signal or framing at the receive terminal. A yellow alarm indicates the loss of signal or framing at the distant terminal. A local failure (red alarm) causes a yellow alarm to be transmitted by forcing bit 2 for each channel to zero in the transmitted DS1 bit stream. A terminal service failure initiates a carrier group alarm (CGA). Trunk channels are forced into a disconnect and make busy (DMB) condition at both ends. The system is automatically restored to service when the alarm condition is cleared.

3.5.3 An M1C multiplexer failure indication is transmitted in the "M" bits used for framing in the DS1C bit stream. An M bit begins each of the four subframes. The M bit pattern is transmitted as 011X. When X=0, a multiplexer alarm condition is being transmitted; X=1 indicates a normal condition. Other "M" type multiplexers use a similar alarm bit sequence.

3.5.4 Digital subscriber carrier terminals generally use the same basic red and yellow alarms described for trunk terminals. Subscriber channels are generally forced into a disconnect and make idle condition

during a service failure to avoid permanant central office seizures. Subscriber carrier systems generally provide a number of other simple alarm functions as a part of the basic equipment. Subscriber terminal alarm information is transmitted to the central office as a part of the bit stream. Examples are subscriber terminal ac power failure, battery charger failure, housing door open, and other abnormal conditions that may soon affect service. These alarm conditions may be retransmitted to a central location as major and minor alarms, or as specific alarms.

3.5.5 Some maintenance and test features are standard in D3 and D4 trunk channel banks. Basic transmission tests and alignment can be made at one end of a system with the channel bank in a "looped" mode. Test codes can be generated to digitally provide 1000 hertz or other frequency at zero dBm0 to align receivers; transmitters can then be aligned by using these precisely aligned receivers. To isolate noise between a transmitter and receiver, an all ones code (except framing) can be sent. All ones represents no voice signal, or a digital quiet condition.

3.5.6 Independent manufacturers enhanced these basic test features, and extended them into subscriber service. Remote testing of equipment and facilities becomes more desirable as the distances between equipment locations and available personnel increase. Many equipment and facility faults can be determined from the CO terminal, and from a centralized test location. Remote testing of subscriber carrier equipment and associated cable facilities for the carrier equipment and for the subscriber drops can be done in varying degrees, depending on the equipment. The test and control signals are transported as specified bits in the bit stream, in carrier derived voice frequency circuits, and/or over express cable pairs to the remote locations. If the subscriber terminal is sufficiently large, it may economically be treated as a central office or major "wire center" for remote testing.

3.5.7 The introduction of new digital alarm and maintenance systems is expected to continue. Standardization is lacking except for very basic alarm and maintenance features. This situation is not expected to change in the near future. The rapid development pace of digital hardware can be expected to promote competition and improvement of new hardware, but tends to discourage standardization.

3.6 <u>Digital Interface</u>: The transmission of information in digital format and the modular characteristics of digital system hardware make it practical to operate transmission and switching as separate or integrated systems. An integrated digital network can be formed with currently available hardware. There is a standard digital transmission hierarchy for the trunk network based on the D3 channel bank and T1 transmission as a basic building module. The DS1 trunk interface is universally accepted by manufacturers in the USA. For better transmission efficiency, much of the transmission equipment for use at rates higher than DS1 does not follow the standard DS hierarchy. There is even less standardization of equipment used for subscriber service. There is a high probability that transmission and switching equipment from different manufacturers will only interface on an analog voice frequency basis except where it has been specified to interface in the defined Bell System hierarchy. It is for this reason that digital subscriber carrier, digital concentrators and other non integrated digital subscriber equipment will continue to maintain a strong role in subscriber service.

3.6.1 The following is a brief discussion on the use of D3 (and D4) trunk carrier channel banks and PCM (D3) subscriber carrier applied in the network on a digital interface basis. While other digital hardware may be mentioned briefly, they are generally covered in other sections. While compatibility of digital interfaces is assumed to exist for purposes of this discussion, digital interface compatibility is unlikely for different manufacturers' equipment. Absolute synchronization is not practical; relative synchronization is achieved through the use of buffer stores.

3.6.2 In rural areas, trunks are most often provided by D3 channel banks over T1 carrier. With the introduction of digital switching, the bit streams from D3 channel banks may enter the digital network and be switched one or more times by digital switches before being decoded at some distant location. Decoding at the distant location may be accomplished by another D3 (or D4) channel bank, or by digital central office equipment. Switching and even the insertion of loss can be accomplished digitally by the rearrangement or other alteration of the digital bit stream.

3.6.3 The potential economic and technical advantages for integrated transmission and switching are significant, especially for subscriber services. On the technical side, the voice could be encoded at or near the calling subscriber's telephone set and decoded at or near the called subscriber. The quality of the circuit would depend almost entirely on the characteristics of a single encoder and decoder. The signal would be affected little by the digital transmission and switching path. One minor exception is that a digital COE is synchronized on a frame basis, and not a super (12) frame basis. The least significant bit (LSB or B8) is robbed for signaling each sixth frame. The lack of super frame synchronization, increases the probability of robbing this voice bit for other frames each time the bit stream is switched. Eventually the LSB will be completely lost; but voice quality will remain good if there is only one (or few) analog to digital conversions in the transmission path. Another technical advantage of integrating transmission and switching is for data transmission. The digital bit stream provides for wide band data (56 kb/s per voice channel plus signaling) and is more immune to interference than analog techniques. Where digital data is switched, digital attenuators should not be used. The digital attenuator would restructure the eight bit code, and change the data bit stream.

3.6.4 For a relative economic comparison, the hardware required for analog and digital interfaces into a digital COE are compared. Items that are common to both digital and analog are excluded.

3.6.4.1 <u>D3 Trunk</u>: For 24 trunks, the analog interface would require a D3 channel bank and 24 CO trunk circuits including encoders. For the digital interface, a DS1 buffer store is required. The channel bank and buffer store costs are somewhat offsetting; the savings would be roughly that of the CO trunk circuits. However, this may be more than offset by the added complexity of the COE if such things as digital attenuation or special software and programming is required.

3.6.4.2 <u>PCM Subscriber</u>: The comparison for PCM subscriber carrier is essentially the same as for D3 trunk carrier.

3.6.4.3 Carrier-Concentrator: There can be some savings when the PCM subscriber carrier and a concentrator are integrated into a common unit. A carrier-concentrator is applied as a separate system from the COE and interfaces the COE on an analog voice frequency basis. These systems generally use a codec per channel and operate in a manner similar to a digital COE and remote switching terminal (RST), except they are far less complex. If the subscriber terminal of a carrier-concentrator were arranged for a direct digital interface to a digital COE, this would eliminate the need for the CO terminal and for CO line circuits. In this application, the unit ceases to be a carrier-concentrator and becomes an RST.

4. RECOMMENDATIONS

4.1 Generalized recommendations on the selection and application of digital transmission equipment are briefly summarized. Included items are trunk and subscriber terminal equipment, multiplex equipment, alarm and maintenance considerations and integrated transmission and switching. There is a variety of hardware currently available and more under development. The application engineer has a variety of choices, but few specifically defined guidelines in making these choices.

4.2 To minimize obsolescence, the following recommendations are made. Choose among the latest models of equipment that have a demonstrated reliability record. Select equipment that meets industry interface compatibitity standards, or meets the key areas of those standards. Where standardization does not exist, compare costs over the projected life of all hardware and software. The lack of standardization for digital hardware and software for subscriber services combined with the rapid introduction of new systems is expected to accelerate software and equipment obsolescence--especially those interfacing switches on a digital basis. Thus, the initial savings of larger integrated systems should be compared to the flexibility of smaller separate transmission systems for subscriber service. While recommendations are not included in earlier paragraphs, the discussion on digital transmission equipment and techniques in paragraphs 2 and 3 may be helpful in choosing the most appropriate equipment.

4.3 Trunk Terminal Equipment: Channel banks for trunk service should be chosen for economy, compatibility, flexibility and ease of maintenance. There are several D3 and D4 types of channel banks in service in rural areas. In general, this equipment has a reliable service record. Later systems using more recent technology have improved transmission characteristics, lower power consumption and are generally lower cost. Obsolescence of earlier channel banks have been a concern, especially for smaller telcos. The impact of channel bank obsolescence is minimized by the relatively low cost and by standardization. Older systems can be removed from service one channel bank at a time, and then used as spares for other equipment still in service.

4.4 Subscriber Terminal Equipment: Each digital subscriber system is generally unique. Few components are likely to be interchangeable with other trunk and subscriber equipment. The use of integrated switching and transmission systems can result in significant initial savings. But careful planning is needed to minimize the impact of obsolescence. Because standardization is limited in this area, there can be advantages in choosing smaller separate transmission systems for subscriber service. Separate systems can be relocated with minimal concern about central office hardware

and software interface.

4.4.1 Subscriber terminals should be located for easy access. Equipment enclosures range from very small housings to prefabricated or masonry buildings. The enclosure choice should be guided by installation size, frequency of site visits expected, climate, right-of-way availability, land costs, etc. Since enclosure costs can exceed equipment costs, options should carefully be reviewed. With minor exception, ac power is required at all digital carrier subscriber terminals.

4.5 Multiplex Equipment: The multiplex equipment used in rural applications is generally designed for efficient use of spectrum, rather than complete standardization. Low density radio and optical fiber applications were not envisioned when the Bell System digital hierarchy was established. It is recommended that multiplex equipment continue to be selected on the basis of efficient spectrum use except where complete standization is a necessary requirement. Partial standardization at DS1 or other levels provide for economical interface of these systems without complete standardization. New intermediate standards may emerge, especially for systems applied to optical cables. In quantity production, multiplex equipment costs might be significantly improved. The greater costs are now in the facility (cable, fiber or radio); thus efficient use of spectrum generally outweighs the benefits of complete standardization.

4.6 Alarms and Maintenance: Alarm and maintenance systems in terminal and multiplex are varied. There is much to offer in these integrated and separate systems, but standardization is limited to the basic features specified for D type channel banks for trunk service and M type multiplexers. Lacking standardization in subscriber, alarm and maintenance techniques, it is difficult to offer specific recommendations. It is recommended that all digital systems contain basic alarm and maintenance systems to minimize the period subscribers will be without service during failures. More elaborate alarm and maintenance systems should be compared primarily on an economic basis. The additional equipment costs should be offset by improved service and improved operating costs.

4.7 Software Compatibility: The rapid developments in microprocessors require additional attention in the area of compatibility. As digital systems incorporate more microprocessors for signaling, testing, automated alarms and other functions, the potential for incompatibility increases for transmission systems and for integrated transmission and switching. Microprocessor operations generally require acknowledgement of execution commands. The speed of operation is limited by the round trip delay of the transmitted and received signals. Equipment performance is optimized between operation speed and application limits. The application engineer must consider not only hardware and function compatibility, but maximum system length and other software compatibility factors. It is recommended that the engineer outline all present and future system requirements, and to obtain written assurances from the Seller before equipment is purchased.

FIGURE 1

D3 CARRIER TRANSMITTER AND RECEIVER

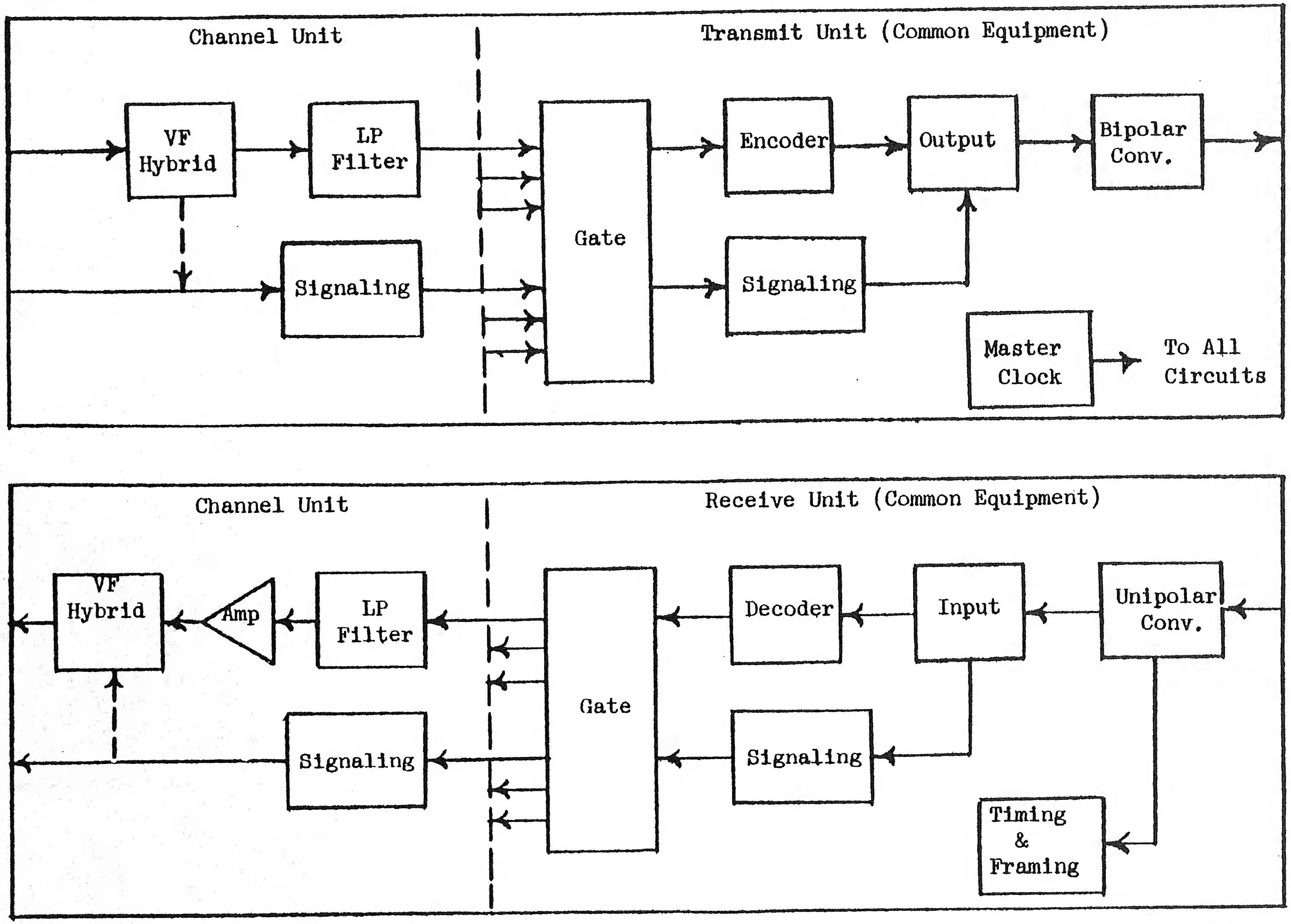
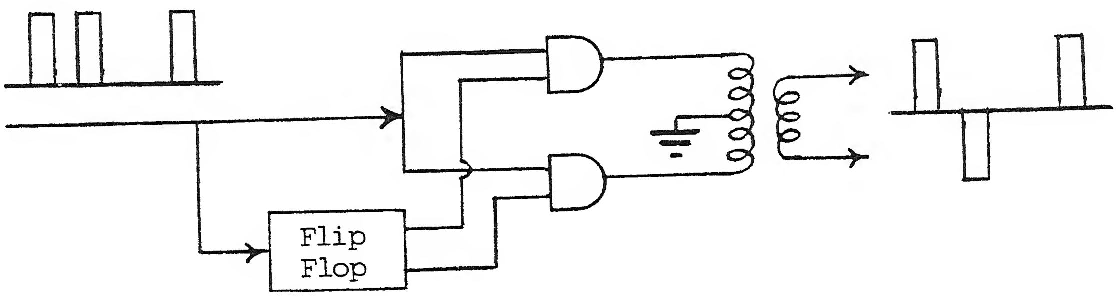


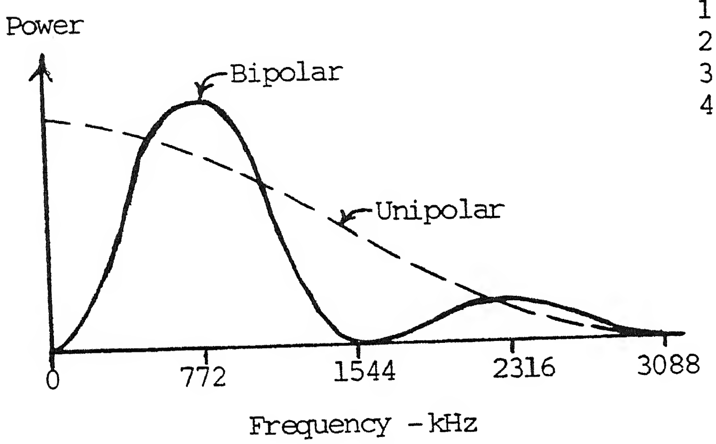
FIGURE 2

UNIPOLAR AND BIPOLAR PULSES

A. Unipolar to Alternate Bipolar Conversion



B. Power Spectrum (T1)



Reasons

1. Power Near 772 kHz
2. LF Power Reduced (No DC)
3. HF Power Reduced
4. Errors Recognized

FIGURE 3

D3 CHANNEL BANK

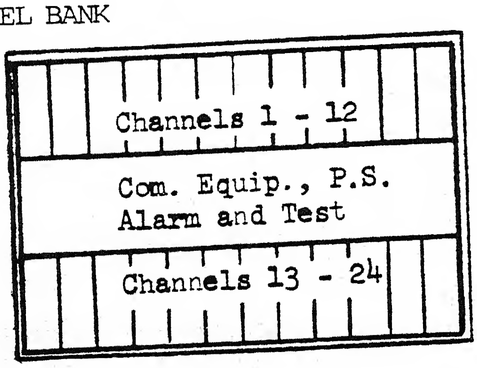
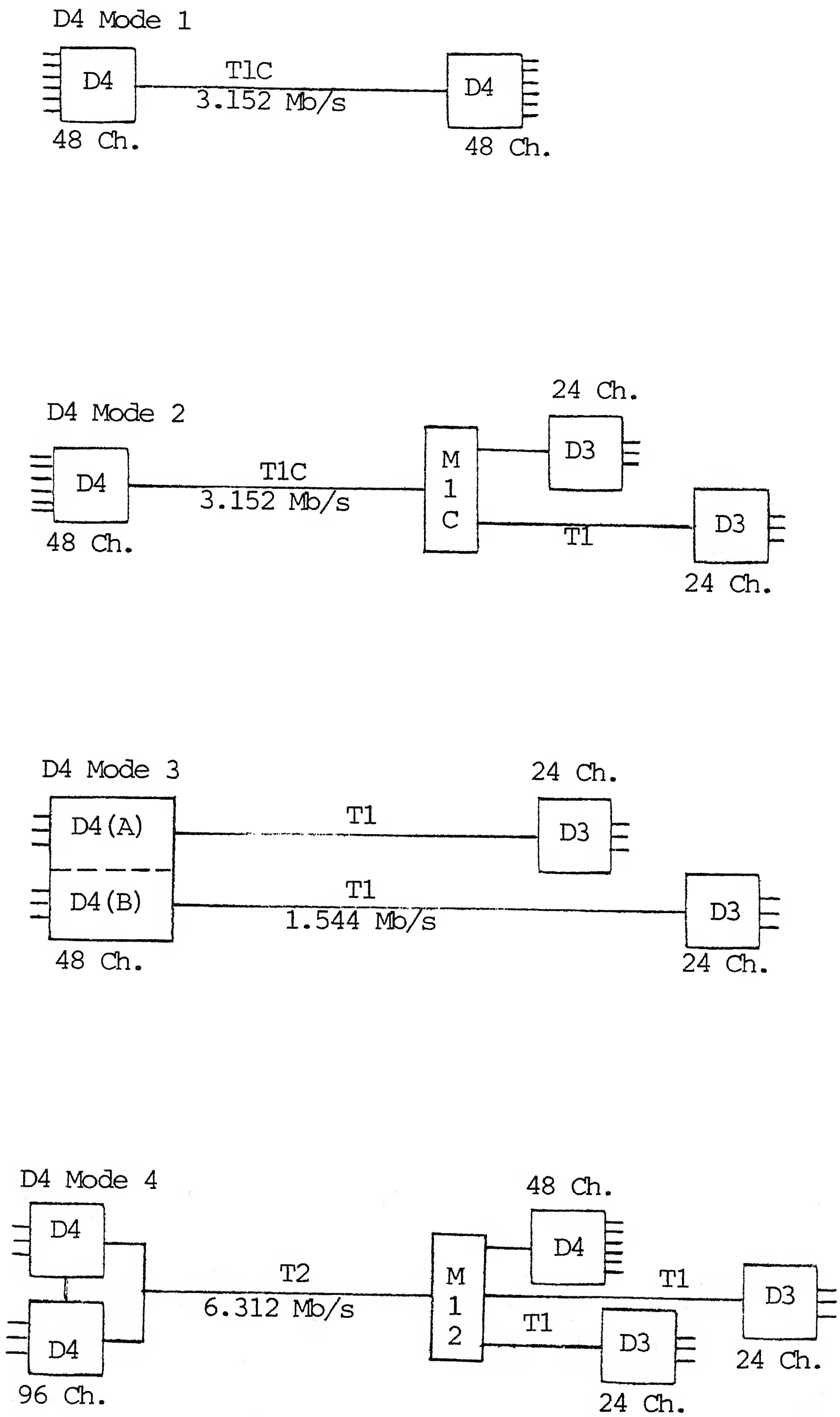


FIGURE 4

D4 CHANNEL BANK: MODES 1-4



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